Fine steel cord with a low structural elongation

Field of the invention.

The invention relates to a fine steel cord for reinforcing a synchronous
belt.

Background of the invention.

Synchronous belts have found their way in many precision machines; in
automobiles, in computer peripheral apparatus such as printers and
copying machines, in positioning systems and in many other
applications. In the art they are also known under other names such as
'toothed belts', 'transmission belts' or 'timing belts'. In what follows, the
terms and definitions according the standard ISO 5288-1982 will be
adhered to. Industry standards DIN 7721-1989 and ISO 5296-1: 1989
define the sizes and tolerances of commercially available synchronous
belts. Synchronous belts are applied where power transmission or
precise longitudinal continuous or stepped displacement of the belt or
precise angular positioning over a longer distance is of the essence.
One of the main requirements posed to a synchronous belt is the
tolerance on the pitch length (see ISO 5288 for the definition), which on
its turn determines the tooth pitch. Depending on the size of the belt the
pitch length tolerance varies from ± 0.28 mm on a pitch length of 100
mm (0.28%) to ± 1.46 mm on a pitch length of 3620 mm (or 0.04%, see
DIN 7721). In practice the tolerances as set forth by the DIN 7721
standard are not longer sufficient as uses of synchronous belts are
spanning longer distances or require better precision control. Also the
fitting between belt tooth and gear wheel has to remain very precise
during the use of the belt. The above mentioned tolerances only apply
for unused synchronous belts. Any misfit during engagement of the tooth
into the gear recess will lead to premature wear of the belt or even teeth
jumping out of the gear. The problem of 'dimensional control' has thus
emerged for synchronous belts.

Over the years fine steel cords has become a preferred reinforcement
for synchronous belts due to their high resistance to creep and the high
modulus compared to other materials. Multistrand (e.g. 7x3, 3x3) cords
remain the preferred type of reinforcement. The configuration where the
strands have the opposite lay direction of the cord ('s' strands in a 'Z'
cord - or sZ for short - and vice versa zS) is preferred due to its better

torsion behaviour although other cords where strands and cord have equal lay direction (sS or zZ) are known with controlled torsion behaviour (US 5 784 874).

Multistrand cords were widely used in the past for the reinforcement of

5   radial tires. Load-elongation diagrams of all multistrand cords known in the art do not show a linear elastic behaviour from the start of the curve onward: there is a small offset of the linear part attributed to the (re) arrangement of filaments and strands in the cord upon loading or unloading. This offset is called 'structural elongation' (see infra) and is

10   never smaller than 0.090 %. It is found that this 'structural elongation' is even more pronounced when using finer filaments to make the multistrand cord.

During the manufacturing of the synchronous belt the fine steel cords are unwound with a low pay-off tension from spools mounted on a creel

15   before entering the elastomer. These forces are not high enough to completely eliminate the structural elongation. Upon pre-tensioning the synchronous belt between the toothed wheels the remaining structural elongation of the cords will lead to out of specification tooth pitch and the problems associated with this. Up to now, belt manufacturers have

20   compensated the dimensional control problem by (see e.g. 'Antriebstechnik 38 (1999) Nr. 5, p. 71-73'):

-       Producing toothed belts with a tooth pitch at the lower dimensional specification which compensates for the structural elongation of the fine steel cords and/or

25   -   Adding additional reinforcement so that the total longitudinal stiffness of the belt increases thus reducing the structural elongation and also increasing the overall modulus of the reinforcement leading to less elongation difference between the loaded and unloaded part of the belt cycle.

30   Both of these solutions have their drawbacks in terms of more rejects and/or more expensive belts.

Belts are manufactured wider and wider as this is more productive as they are slit afterwards into smaller belts. However, with increasing width the synchronous belt production is more susceptible to the 'curling'

35   effect (when hanging a piece of the belt freely, the free end turns with

respect to the fixed end) or the 'sabre' effect (a piece of the belt laid down on a flat surface is not straight, but curved). Both effects are very detrimental in the use of the belt, as they tend to derail the belt from the gear wheel.

5   Multistrand cords are made in a two-step process. In a first step filaments are twisted to a strand with a particular lay length and direction onto a strand spool. In a second step a number of strands are pulled-off from the strand spools and twisted to a cord with a specified lay length and direction. Either one or both of the twisting steps can be performed
10   in a cabling machine or alternatively in a bunching machine. In the art, the latter technology is preferred due to its higher twisting speed and due to the larger spools that it allows for. However, in case the cord is of the sZ type - or its' mirror image the zS type - and the cord is twisted in a bunching machine, account has to be taken for the number of twists that
15   are taken out of the strand by the bunching operation. If we denominate the number of twists of the strands per unit length of finished cord by N_c and the number of twists of the filaments per unit length of strand in the finished cord as N_s then the strands have to be twisted up to N_s+N_c twists in order to end with N_s twists per unit length of the strand in the
20   final cord.

Summary of the invention.

The inventors have found a different solution to solve the 'dimensional control problem' of synchronous belts, which is a first object of the
25   invention. Surprisingly their solution also solved the 'curling' and 'sabre' effect. In addition their solution also increased the overall modulus of the cord in the working region of the belt thus reducing the elongation of the belt between loaded and unloaded part of a belt cycle without having to use more reinforcement material: a second object of the invention. The
30   inventors have found a method to produce the multi strand cords in an efficient way: a third object of this invention.

The invention relates to the combination of features as described in claim 1. Specific features for preferred embodiments of the invention are
35   set out in the dependent claims 2 to 6 and 10 to 13. The invented

method is comprised by the combination of features as described in claim 7. Specific features of preferred methods are in claims 8 and 9. The use of the fine steel cord as a reinforcement for synchronous belts is claimed in claim 14.

According a first aspect of the invention a fine steel cord for reinforcing a synchronous belt is claimed. Plain carbon steel is preferably used. Such a steel generally comprises a minimum carbon content of 0.40 wt% C or at least 0.70 wt% C but most preferably at least 0.80 wt% C with a maximum of 1.1 wt% C, a manganese content ranging from 0.10 to 0.90 wt% Mn, the sulfur and phosphorous contents are each preferably kept below 0.03 wt%; additional micro-alloying elements such as chromium (up to 0.2 to 0.4 wt%), boron, cobalt, nickel, vanadium – a non-exhaustive enumeration– may also be added. Also preferred are stainless steels. Stainless steels contain a minimum of 12 wt% Cr and a substantial amount of nickel. More preferred are austenitic stainless steels, which lend themselves more to cold forming. The most preferred compositions are known in the art as AISI (American Iron and Steel Institute) 302, AISI 301, AISI 304 and AISI 316.

The fine steel cord comprises at least two strands, each of said strands comprising at least two steel filaments. The filaments have dimensions ranging between 30 μm and 250 μm but most preferred are sizes between 40 and 175 μm. The most preferred filament size is between 120 to 160 μm. As these filaments are relatively thin compared to tire cord filaments, the cords resulting from them are therefore called 'fine'.

It is not necessary that all filaments have the same diameter although it is preferred because it is convenient in the production. Different filament diameters within the same cord can be chosen in order to fit them better together or they may be chosen in order to generate gaps between the filaments in order to allow for elastomer penetration.

The filaments used can be without any coating. Or the wires can be coated with a suitable coating. Preferred are:

- electrolytically applied brass having a composition of between 62.5 and 75 wt% Cu, the remainder being zinc. The total coating mass is between 0 to 10 g/kg.
- or the wires can be coated with zinc with a coating mass ranging from 0 to 300 g of zinc per kg of wire. The zinc can be applied onto the wire by means of an electrolytic process or by means of a hot dip process, followed or not followed by a wiping operation in order to reduce the total weight of the zinc.

Because of the corrosion protection of zinc and the presence of an iron zinc alloy layer that forms during the hot dip operation, the latter coating type is most preferred. Other coating types such as zinc alloy coatings e.g. a zinc aluminium alloy (e.g. having an eutectoid composition of about 95wt% zinc and about 5wt% Al) or even ternary alloys are not excluded. It should be clear that the enumeration of coating types is non-exhaustive.

The filaments are twisted together with a certain lay direction and a lay length. Typically the lay length is from 10 to 40 times the diameter of the strand. More preferred is a lay length between 20 to 30 times the diameter of the strand. The strands are twisted together to a cord having a lay length of between 5 to 20 times the diameter of the cord. More preferred is a lay length between 7 and 14 times the diameter of the cord.

The following combinations of filaments are known in the art:
- 3 strands each containing 3 filaments. In shorthand: 3x3
- One 3-wire core surrounded by six 3-wire strands: 7x3
- One 4-wire core surrounded by six 3-wire strands: 7x4
- One 3-wire core surrounded by five 7-wire strands: 3+5x7
- One 7-wire core surrounded by six 7-wire strands: 7x7
- One 19-wire core surrounded by eight 7-wire strands: 19+8x7
- One 19-wire core surrounded by nine 7-wire strands: 19+9x7

These combinations are only given by way of non-exhaustive examples. There are numerous cord combinations known in the art, which are envisaged in this invention, as long as they are composed out of at least two strands possibly, wound or not wound around a core.

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The cords according the invention have strands with a lay direction opposite to the lay direction of the cord. E.g. if the strands have a lay direction in S, the cord will have a lay direction Z. The lay direction of the core - if present - is immaterial: it can be either S or Z.

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The features of the load-elongation curve that are of importance to understand the invention are illustrated in Figure 1. The fine cords that are object of this invention show a very distinct load-elongation behaviour compared to state-of-the-art fine cords. This behaviour can be

10   best distinguished by subjecting the cords to a cyclic loading between a low load and a high load. A 'low' load is e.g. the load used during manufacturing of the belt: 10 to 50 N is customary. A 'high' load is e.g. the load on the cord during use of the belt in the loaded part of a belt cycle. Belts are normally subjected to a maximum of 20 to 30% of their

15   nominal breaking load. As these exact loads are not generally available, the inventors preferred to use as a 'low' load a load equal to 0.2% of the breaking load of the cord and as a 'high' load a load equal to 20% of the breaking load of the cord. The cyclic loading and unloading of a cord between defined forces is a well-known test in the field of steel wire

20   ropes (see K. Feyrer, "Drahtseile, 2.Auflage", page 85).

The load-elongation curves are taken over different cycles between the low and high load, the reason being to be able to distinguish between the phenomenon of the 'setting of the cord' (Figure 1, 'A') and the

25   'structural elongation' (Figure 1, 'B'). The 'setting of the cord' is a first time adjustment of the filament positions leading to a small permanent elongation. After the first loading this 'setting of the cord' has disappeared. 'Structural elongation' remains after repeated loading. Typically 20 cycles are used in order to ascertain that the cord has fully

30   settled although in practice the curve does not alter anymore after about 10 cycles.

Load - elongation diagrams of fine steel cords exhibit a linear portion (with an elongation interval indicated with 'D' in figure 1) between

35   approximately 10 to 60% of their breaking load before showing non-

linear plastic deformation at higher loads (with an elongation interval 'C' indicated in Figure 1). Hence the 20% of the breaking load is within this linear portion. This linear portion must be extrapolated backwards (indicated by the line 'E' in Figure 1) - in the direction of lower loads - in order to establish the 'structural elongation'. The 'structural elongation' ('B' in Figure 1) is now defined as the difference between the elongation at 0.2% of the breaking load of the backwards extrapolated linear behaviour with the elongation at 0.2% of the breaking load of the true curve.

As the filaments rub over one another the cyclic load - elongation diagram shows hysteresis i.e. the loading and unloading curve do not coincide completely and form a closed loop ('H' in Figure 1). Therefore it is here understood that the structural elongation must be defined on the return cycle i.e. in going from 20% of the breaking load to 0.2% of the breaking load.

Fine steel cords according the invention have a structural elongation below 0.09 % (claim 1) and preferably below 0.06% (claim 2).

A further characteristic of the invention (claim 3) is that the load-elongation curve below 20% of the breaking load does not show the non-linear curve as is typical for the state-of-the-art cords. The elongation behaviour of the cord at loads below 20% of its breaking load fairly accurately follows a linear Hooke's law. The load-elongation curve of the invention cords remains between two straight lines that are separated by an elongation of 0.06% thus confining the load-elongation curve in a straight band. The load-elongation curves remain in this band from the second cycle onward – i.e. excluding the 'setting of the cord' – up to the twentieth cycle.

Also the slope exhibited by this band is markedly different from that of the prior art cords. If we consider the slope between the lower - i.e. the turning point at 0.2% of the breaking load - and upper turning point - i.e. the turning point at 20% of the breaking load - divided by the metallic

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surface of the wires as an 'equivalent elongation modulus' (as illustrated by the slope of line 'G' in figure 1), the invention cords have an equivalent elongation modulus exceeding 150 000 MPa (claim 4) and more preferably exceeding 170 000 MPa (claim 5). This is already much closer to the theoretical achievable maximum of about 200 000 MPa for a single wire. This equivalent elongation modulus is also known as the secant modulus between defined forces (see K. Feyrer, "Drahtseil, 2. Auflage", page 81)

In combination with the features above a favourable setting of the cord is claimed (claim 6). The 'setting of the cord' can be conveniently quantified as the elongation at first cycle, the cycle comprising: pre-tensioning the cord at 0.2% of its breaking load, loading the cord to 20% of its breaking load followed by unloading the cord to 0.2% of its breaking load. The elongation then measured is the 'setting elongation' (see 'A' of Figure 1). It will be clear to the person skilled in the art that 'the setting of the cord' can only be determined on cords that have not been loaded before. This setting elongation remains below 0.03% for the invention cords.

The fine steel cord can also be coated with an elastomer coating (claim 10). By preference this coating encloses a single fine steel cord and is round and thin. The elastomer is by preference polyurethane as this is the material normally used to make timing belts and is therefore compatible (claim 11).

Such a coating must adhere well to the fine steel cord in order to maintain the integrity of the composite during use (claim 12). Adherence of the cord to the elastomer can be assessed through the ASTM 2229/93 pull-out test. Typically the pull-out force of the fine cord - having a diameter 'D' expressed in mm - embedded in an elastomer over a length 'L' must be larger than 40×D×L Newton, but most preferred is if the elastomer adheres to the cord with a pull-out force that is larger than 50×D×L Newton.

The penetration of the elastomer greatly helps to keep the filaments 'in place' during their use. It is therefore preferred that the elastomer

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penetrates at least the outer strands of the cord. Most preferred is that all individual filaments are completely surrounded by polymer over substantially the length of the fine cord (claim 13).

5   The inventors have also observed another unexpected advantage of the inventive cord: the spread of all parameters - and most notably the structural elongation - in the load-elongation curve is lower for the inventive cords compared to the spread for the conventional cords. 'Spread' in this context has to be considered as the long-term variation

10   from production run to production run. The reduced variation can easily be understood from the fact that a structural elongation below zero is simply not possible. The inventive cords are 'calibrated' against the theoretical cord having a zero structural elongation. As such they will have a much lower spread compared to conventional cords where in the

15   latter the structural elongation can wander in both directions.

From the above it will be clear for the person skilled in the art that the determination of the different product parameters is not so much dependent on the 20% load limit during the measurement, as long as

20   this 'high load' is situated in the linear portion of the curve. Hence, a 'high load' of 30, 40 or even 50% of the breaking load, will lead – within the measurement uncertainty – to identical results for the product parameters. However, the opposite is true for the 'low load': there the measured product parameters clearly depend strongly on the value of

25   the lower load due to the non-linear behaviour of the conventional cord.

It will also be clear that the measurement of the above parameters must proceed with the appropriate apparatus having the necessary accuracy and precision. In particular the load cell must be appropriate for the low

30   loads involved and the elongation must be precisely measured by means of an extensiometer. Also the apparatus must be capable of cycling the load. Although the measurement requirements are high, today's state-of-the-art measuring equipment is capable of fulfilling these requirements. The curves in this application have been generated on a

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Zwick (Ulm, Germany) BZ020/TH2S apparatus controlled by the "testXpert V8.1" software.

All the product features as described in the claims 1 through 6 are the consequence of the processing of the cords only. Indeed, the invention cords do not discriminate themselves from the state-of-the-art product in terms of known structural features such as steel composition, coating, filament diameters, strand and cord lay lengths. For example the increase in equivalent elongation modulus as claimed in claim 4 and 5 has nothing to do with a change in lay length of the cord: they are exactly the same between invention cords and state-of-the-art cords. This feature is particularly mentioned, because it is known in the art that increasing the lay-length of the cord increases the modulus.

The second aspect of the invention concerns a method to produce the inventive cord. According this method the needed strands are produced having a number of twists n_s of at the most N_s i.e. the number of twists the filaments must have in the strand of the final cord. Each of the necessary strand spools is mounted in an individual twister pay-off. A twister pay-off is a pay-off system that is able to increase the number of twists per unit length in the strand when turning in the same lay direction of the strand. Mutatis mutandis, the twister pay-off is able to reduce the number of twists per unit length of the strands when it is turning in the direction opposite to the lay direction of the strand. The number of twists added or subtracted is proportional to the ratio of rotational speed of the twister to the linear speed of the strand. Preferably the rotational speed is adjustable. Most preferable is that both speeds are adjustable.

All strands are lead to the assembly point at the entrance of a bunching machine. There the strands are assembled into a cord. The strands obtain N_c twists per unit length. As the lay direction of the cord is opposite to the lay direction of the strands, the strands are untwisted with N_c twists per unit length. The rotational speed of the twister pay-off must be adapted in order to obtain the correct number of twists per unit

length of the strand in the final cord. Finally the cord is wound on a cord spool at the inside of the bunching machine.

The inventors have found that in order to obtain the fine cords as claimed, the number of twists per unit length that a strand locally obtains along its track from strand spool to cord spool must be minimal, i.e. definitely below $N_c + N_s$ and preferably close to N_s, while even below N_s before entry in the cord is not excluded. Any excess of twists given to the strands – even if these twists are finally taken out of the strand upon bunching of the cord – leads to 'looseness' of the strands, which is reflected in the undesired structural elongation, causing the dimensional control problem of the synchronous belts. Although the above simply and clearly reflects the spirit of the invention, the reduction into practice of this insight required some non-obvious changes in the process.

A first way to implement this insight was to increase the pay-off tension to an unusual high level as described in claim 7. The pay-off tension is most conveniently expressed in terms of the ultimate breaking load of the strand. At least the pay-off tension must be higher than 15% of the strand's breaking load. Preferably it is above 20%. By increasing the pay-off tension, a torque is exerted on the strand that therefore tends to untwist and thereby starts to rotate during its travel from strand spool to cord spool. Due to this rotation, the total number of twists of the strand before entry into the cord is lowered.

A second important feature of the method is that the entrance pulley of the bunching machine must be put under an angle with respect to the plane formed by entering and exiting cord (claim 8). After this pulley the cord is guided in a bow towards the reversing pulley at the end of the bow. Preferentially these pulleys are grooved. Even more preferred is that these pulleys have a U shaped grove larger than the diameter of the cord. Normally the rotational axis of the entrance pulley is perpendicular to the plane formed by entering an exiting cord i.e. directed along the normal of that plane. According to the invention the entrance pulley axis is inclined with respect to this normal. The inclination is set such that the

cord rolls in the U shaped groove in its closing direction. The closing direction is the rotational direction in which the number of twists on the cord increases. More preferred is that the axis of the pulley is rotated around the bisector of the lines formed by the entering and exiting cord. Even more preferred is that both entrance and reversing pulley are put under an angle (claim 8). The principle of putting the entrance and reversing pulleys under angle is to shift the point where the strands in the cord obtain their final number of twists to the assembly point. In this way the untwisting of the strands in the bow of the bunching machine is prevented. For clarity: in a state-of-the art bunching machine (no pulleys under angle) the cord receives half of its final number of twists at the entrance pulley and the other half of its final number of twists at the reversing pulley. Hence the strand is untwisted during its travel in the bow of the bunching machine while it gets its final position in the cord. In the cord the strand is thus fixed in a loosened state causing again too high structural elongation, which on its turn leads to the dimensional control problem of synchronous belts.

A third feature of the invented method relates to the path the strand travels from strand spool to cord spool. There the inventors found that the path must not be obstructed by any type of guiding pieces, rollers, pulleys or any other device that could impede the rotation of the strand. Any of such devices leads to a restriction of the untwisting by the bunching machine, which should be prevented according the invention (claim 9).

According a third aspect of the invention, the use of such cords for the reinforcement of synchronous belts is claimed (claim 14). Such a belts have an excellent dimensional control and remain stable during use.

Brief description of the drawings.

The invention will now be described into more detail with reference to the accompanying drawings wherein

- FIGURE 1 :   Depicts a typical load-elongation of a fine steel cord, with the parameters of importance.

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- FIGURE 2 :   Shows the load elongation diagram of a fine steel cord of
               type 7x3x0.15 according the prior art and according a first
               preferred embodiment.

- FIGURE 3 :   Shows the load elongation diagram of a fine steel cord of
               type 3x3x0.15 according the prior art and according a second
               preferred embodiment.

- FIGURE 4a: Illustrates the prior art production method and the
            inventive production method.

- FIGURE 4b: Illustrates the variation of twists per unit length on the
            strand in their travel from strand spool to cord spool for both the
            state-of-the-art method 'CP' and inventive method 'IP'.

- FIGURE 5:   a drawing of a pulley mountable under angle.

Description of the preferred embodiments of the invention.

In a first preferred embodiment, the inventors have produced a 7x3 type
of cord characterised by the following formula:

$$[(3\text{x}0.15)_{9s} + 6\text{x}(3\text{x}0.15)_{9s}]_{8z}$$

i.e. a core strand consisting of 3 filaments twisted together with a lay
length of 9 mm in S direction is combined with 6 outer strands again
consisting of 3 filaments twisted together with a lay length of 9 mm in S
direction to a cord. The strands are twisted in to the cord with a lay
length of 8 mm in Z direction. The filaments were plain carbon steel
filaments having a carbon content of about 0.725 wt. %C and having a
hot dip galvanised zinc coating. The cord was produced from the
filaments according the conventional process and the inventive process.
The cord has a metal cross-sectional area of 0.371 mm² (acc. DIN 3051
i.e. sum of filament cross sections).

First the conventional process will be explained by means of Figure 4a.
Thereafter the inventive changes to this process will be highlighted. A
strand spool 2 – containing a strand with N_s twists per meter - is
mounted in a twister pay-off system 4. A twister pay-off 1 as known in
the art can be physically implemented by rotatably mounting a spool 2 in

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a stationary hanging cradle (not shown) suspended between two rotation points (not shown). The strand is pulled form the spool through the first rotational point over a revolving reversing pulley or guide piece 4 to the second rotational point where again a revolving reversing pulley or guide piece 5 leads the strand out of the twister pay-off in a direction opposite to the direction in which the strand is pulled form its spool. During its travel from the first to the second pulley the strand maybe guided through a flyer 3 rotating around the stationary cradle. However, embodiments without flyer 3 are also known in the art. Other embodiments of a twister pay-off are known in which the spool rotation axis on its turn rotates around an axis along which the strand leaves the pay-off, the latter axis being perpendicular to the spool rotation axis. Also these embodiments of a twister pay-off are explicitly included in the inventive process. The twister pay-off will add to N_s a number of twists per meter. The added number of twists must correspond to the number of twists of the cord N_c, because the bunching machine 13 will later remove exactly this number of twists. The dashed line between P0 and P2 in Figure 4b schematically depicts the increase of the number of twists per unit length of the strand.

After leaving the twister pay-off at P2 (Figure 4a), the strand is guided over different guiding pulleys 6 such that the strand can conveniently be combined with other strands 7 to form the cord in the assembly point 8. For each strand, an individual twister pay-off must be operated under identical process conditions. At the assembly point 8, the strands are twisted together by the bunching machine 13. Between the assembly point 8 and the cord spool 12, the cord receives N_c twists per meter while the strands are untwisted N_c twists per meter. Due to the working principle of the bunching machine 13, about $N_c/2$ twists are taken out of the strands between entrance pulley 9 and reversing pulley 10 and the remaining $N_c/2$ twists are taken out from the strands between the reversing pulley 10 and cord spool 12. The evolution of the number of twists on the strand is illustrated by the dashed line between P4 and P6 of Figure 4b.

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For the particular embodiment, N_s is (1000/9) twists per meter and N_c is (1000/8) twists per meter. As the cord has a lay length opposite to that of the strands, the strands will be untwisted in their travel from strand spool to cord spool and this must be compensated for by twisting up to
5   (1000/9)+(1000/8) twists per meter, which corresponds to a lay length of 4.235 mm in 's' direction. Figure 4b (the dashed line marked 'CP') illustrates the evolution of the number of twists per meter on the strand in its travel from strand spool to cord spool in the conventional process. It will be clear that the tight twisting of 4.235 mm leaves a helical plastic
10   deformation in the strands when they are untwisted to a lay length of 9 mm. This helical plastic deformation leads to the high structural elongation.

The difference between the conventional process and the inventive
15   process is explained below and summarised in Table 1. Figure 4b, illustrates the difference on the number of applied twists per unit length on the strand for the conventional process (curve 'CP') and the inventive process (curve 'IP').

Process parameter	Conventional process	Inventive process
Initial strand lay length	9 mm	14 mm
Initial strand twists per meter	111 tw/m	71.4 tw/m
Ratio of rotational speed of twister to that of bunching machine	1.000	1.311
Ratio of Strand pay-off tension to Strand Breaking Load	7.7 %	15 %
Pulley angles bunching machine	entrance pulley: 0° reversing pulley: 0°	entrance pulley: 10° reversing pulley: 10°
Number of pulleys from strand spool to cord spool	6	4
Resulting cord	Cord 'CP'	Cord 'IP'

20   **Table 1**

Firstly, the number of twists n_s of the original strands is lower or equal than N_s in the inventive process as indicated in P0 of Figure 4b. Due to this, the twister pay-off must run at a higher rotational speed than the

5   bunching machine in order to get the correct number of twists per unit length in the strands of the final cord.

However, the twists applied are physically prevented of building up to a local level of N_s+N_c by applying a higher pay-off tension to the strands

10   than in the conventional process. By increasing the pay-off tension of the cords, a torque develops in the strand that untwists the strands, thus reducing the number of twists on curve 'IP' in P2 of figure 4b to well below N_s+N_c.

15   A further improvement to allow the free rotation of the strand is the elimination of the guiding pulleys 6 in Figure 4a. Guiding pulleys have the tendency to restrict the rotation of strands as soon as they bend the cord. Because some pulleys have been eliminated the strand twists also do not built up at P3 as shown on curve 'IP' in Figure 4b, P3.

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Another improvement to limit the built-up of twists in the strand is to bring the strand untwisting action of the bunching machine closer to the assembly point 8. This can be achieved by putting the entrance and/or reversing pulley 9 of the bunching machine under an angle as illustrated

25   in Figure 5. There the entering cord 51 is guided over a U grooved pulley 56 and leaves as exiting cord 52. The bisector of the entering cord 51 and exiting cord 52 that is perpendicular to the plane of the paper is noted as 55. The axis of the pulley 54 is rotated over the angle α with respect to the normal to the plane 53 formed by entering cord 1 and

30   exiting cord 2. The direction of the angle should be chosen such that the cord tends to close. By putting the pulleys under angle the cord starts to roll in the U shape of the pulley, twisting up the strands in the cord and hence also untwisting the filaments in the strands. Therefore the cord obtains its final lay length much closer to the assembly point than in the

35   conventional process. Consequently, the strands do untwist during cord

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formation to a much lesser extent then in the conventional process as is illustrated at P4 in Figure 4b (comparing curve 'CP' to curve 'IP').

The difference in load-elongation curves of the cords 'CP' and 'IP' made according the two different processes is depicted in Figure 2. The features of these curves are summarised in table 2:

Product parameter	Cord 'CP'	Cord 'IP'
Cord Breaking Load	920 N (*)	920 N (*)
Low load limit	1.84 N	1.84 N
High load limit	184 N	184 N
Structural elongation on return of 20th cycle	0.160 %	0.018 %
Slope equivalent to an elongation modulus	115 910 N/mm²	175 461 N/mm²
Elongation after 1st cycle	0.006 %	0.012 %

(*) Aim value, not measured.

Table 2

In Figure 2, the identification of the different features as discussed for Figure 1 are used. Added also is a strip 'J' having a width of 0.06% in elongation, illustrating the fact the invention cord remains in between these limits (claim 3).

A second preferred embodiment is a 3x3x0.15 cord of which the table 3 both summarises the processing conditions used and product features obtained. The load-elongation curve can be found in Figure 3. The 3x3x0.15 construction is constructed as follows:

$$[3 \times (3 \times 0.15)_{9s}]_{8z}$$

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Parameter	Conventional process	Inventive process
Initial strand lay length	9 mm	14 mm
Initial strand twists per meter	111 tw/m	71 tw/m
Ratio of rotational speed of twister to that of bunching machine	1.000	1.311
Ratio Strand pay-off tension to Strand Breaking Load	10%	18 %
Pulley angles bunching machine	0°/0°	10°/0°
Number of pulleys from strand spool to cord spool	6	4
Cord Breaking Load	520 N (*)	520 N (*)
Low load limit	1 N	1 N
High load limit	104 N	104 N
Structural elongation on return of 20th cycle	0.105 %	0.020 %
Slope equivalent to an elongation modulus	145 595 N/mm²	185 378 N/mm²
Elongation after 1st cycle	0.047 %	0.015 %

(*) Aim value, not measured.

Table 3

A third preferred embodiment concerns a (3+5x7)x0.15 fine steel cord that can be detailed as follows:

$$[(3\times0.15)_{9\,s} + 5\times(0.15+6\times0.15)_{10\,s}]_{12.5\,z}$$

The cord was manufactured according the standard and the inventive process and the following results were obtained:

Parameter	Conventional process	Inventive process
Cord Breaking Load	1730 N (*)	1730 N (*)
Low load limit	3.46 N	3.46 N
High load limit	346 N	346 N
Structural elongation on return of 20th cycle	0.085 %	0.023 %
Slope equivalent to an elongation modulus	142 000 N/mm²	173 000 N/mm²
Elongation after 1st cycle	0.006 %	0.0085 %

(*) aim value, not measured.

Table 4

In a fourth preferred embodiment, the 7x3x0.15 of the first embodiment was coated with an elastomer coating. Prior to this coating, the cord was cleaned by means of a steam degreasing step. Subsequently the cord was dipped into a solution of 1.5 vol. % of N-(2-amino ethyl)-3-amino propyl tri methoxy silane dissolved in a mixture of isopropanol and water, followed by drying. The use of such organo functional silanes for adhesion promotion is known in the art (see e.g. WO 2004/076327). Subsequently the cord was coated with a layer of Desmopan® 392 from Bayer, enlarging the bare cord diameter from 0.90 mm to 1.00 mm. Coating was performed by means of a standard extruder whereby the steel cord was preheated to 180°C prior to entering the extruder head. Polyurethane was injected into the extruder head at 225°C at a pressure of 100 bar. After coating the coated fine steel cord was cooled in water. Adhesion testing according the ASTM D2229/93 test over an embedment length of 12.7 mm revealed a pull-out force in excess of 929 N as 5 out of the 6 cords broke before the cord pulled of from the polyurethane block which is above the 50×D×L = 575 N limit. In addition, a cross section of the cord revealed that each of the 21 filaments was embedded in PU.

The cord thus coated (Cord 'IP+ PU')showed the same favourable elongation behaviour as the original inventive cord as summarised in table 5.

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Product parameter	Cord 'CP'	Cord 'IP'	Cord 'IP+PU'
Low load limit	1.8 N	1.8 N	1.8 N
High load limit	180 N	180 N	180 N
Structural elongation on return of 20th cycle	0.089 %	0.012 %	0.012 %
Slope equivalent to an elongation modulus	134 000 N/mm²	177 000 N/mm²	177 000 N/mm²
Elongation after 1st cycle	0.002 %	0.007 %	0.002 %

Table 5

In a sixth preferred embodiment, it was verified that the favourable properties were not lost during making of the synchronous belt. A closed loop belt was produced with a 10 mm pitch and a length of 840 mm

5   containing 16 cords of type 7x3x0.15. A first belt was produced with conventional process (CP) cords, a second belt was produced with the inventive process (IP) cords, and a third belt was made with IP cords, coated with PU. The belts had a breaking load of about 15 kN. They were cyclically loaded 10 times from a pretension of 100 N ('Low Load')

10   to 5kN ('High Load'). Although the measuring conditions are not exactly the same as for the cords, a comparison of the relevant parameters can still be made. Table 6 summarises the results:

Cords used...	CP cords	IP cords	IP, PU coated
Structural elongation on return of 10th cycle	0.096 %	<0.010 %	0.038 %
Elongation after 1st cycle	0.041 %	0.034 %	0.032 %
Elongation between high and low load on 2nd to 10th cycle	0.562 %	0.466 %	0.484 %

Table 6

During use, the belts with the IP cords and the coated IP cords, showed

15   a much lower elongation and - consequently - tooth wear than the CP cords. This proves that the inventive cord solves the 'dimensional control' problem.